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LLNL Measurements of Graded-Index Multi-Mode Optical Fiber (ITF 47)

T. T. Saito

May 1, 2000

U.S. Department of Energy

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Livermore
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DISCLAIMER

Work performed under the auspices of the U. S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Lawrence Livermore National Laboratory Measurement of VNIITF Fiber ITF 10.2

Introduction & Summary

Background

The Russian Federal Nuclear Center -All Russian Research Institute of Technical Physics, located in the Nuclear City of Snezhinsk, east of the Ural mountains and the Lawrence Livermore National Laboratories have been investigating the possibility of establishing a commercial optical fiber manufacturing facility. These discussions began in the summer of 1998. At that time three samples (single mode and multi-mode) of optical fiber were left at the Sandia National Laboratory. Sandia measured two of the segments and sent them to LLNL. The optical loss at 1550 nm and 1300 nm were higher than commercially available fiber. The measurements were complicated because the geometry of the fibers also did not meet specification. Since the core was not adequately centered coupling of optical energy into the fiber being tested varied widely depending on which end of the fiber was used for insertion. The results of these measurements were summarized in the informal report dated June 11, 1999, which was hand carried by Dr. Paul Herman during his July 1999 visit.

During the July visit a 1.2-km long section of graded-index multimode fiber, ITF 47, was given to Herman. We had requested samples longer than the earlier ones (which were ~ 0.1 km long) in order that a cutback method could be used for the transmission measurements.

Measurements Summary

The optical loss using the cutback technique and the transmission spectral measurements in the 600-1700 nm region are reported. Also physical measurements are reported of the fiber's diameter, concentricity, ellipticity and tensile strength (proof test). The test results are summarized in Table 1, "Comparative Data for Multi-mode Optical Fiber." The table includes the values from the Industrial specification TIA/EIA 402AAAB, the commercial specification for Corning's 50/125 CPC6, the values measured on ITF-47 and provided by C-70, and LLNL's values for ITF-47 as well as the multimode values from the June 1999 samples.

Physical measurements

Proof Test (Tensile Test) -Set-up

A 10 m long section of the optical fiber was tested on an Instron 1122 test system at a rate of 12.7 mm/min in late September 1999. The load was measured with the 20-lb. range and displacement was calculated from the motion of the crosshead. Five fiber locations were randomly selected from locations within the roll and measured for diameter using a Zygo 1200 Laser, and the outer diameter of the fiber, that is the coating, is given in Table 2. Fiber specimens were gripped with Instron series 2714 pneumatic cord and yarn grips. To minimize crushing of the optical fiber, vinyl tape was applied to grip faces to distribute stress. Grip air pressure of 15 psig was used.

Table 1 - Comparative Data for Multi-mode Optical Fiber

Specification	**TIA/EIA** 402AAAB Industrial spec	**"Corning" 50/125 CPC6**	**ITF-47 C-70 Values**	**ITF-47 LLNL Values**	**ITF-10.2 Multimode LLNL**
1	2	3	4	5	6
1. Core Diameter, μm	50.0 ± 3.0	50.0 ± 3.0	51	53 ± 2	
2. Cladding Diameter, μm	125.0 ± 2.0	125.0 ± 2.0	127	128 ± 1	
3. Coating Diameter, μm	250.0 ± 15.0	245.0 ± 10.0	270	270 ± 6***	
4. Core-Clad Concentricity, μm	≤ 3.0	≤ 3.0		0.7	
5. Coating-Cladding Concentricity, μm	≤ 20	≤ 12			
6. Cladding Non-Circularity, %	≤ 2.0	≤ 2.0	4	0.7	
7. Core Non-Circularity, %	≤ 6.0	≤ 5.0	4	0.8	~14
8. Standard Length, M	1100 - 4400	1100 - 4400	1300		
9. Proof Test, Gpa	≥ 0.69	≥ 0.7	0.4	0.9	
10. Attenuation, λ =850nm, dB/km	≤ 3.0	≤ 2.5	3.0	7 @ 830 nm	
11. Attenuation, λ =1300nm, dB/km	≤ 1.0	≤ 0.8	1.2	5 ****	
12. Attenuation, λ =1380nm, dB/km	≤ 3.0	≤ 2.0	9.0	16****	2.4 @ 1550 nm
13. Bandwidth, λ =850nm, MHz-km	≥ 400	500	380	1,100 MHz-km @ 832 nm	
14. Bandwidth, λ =1300nm, MHz-km	≥ 400	500	500		
15. Zero Dispersion Wavelength, nm	1295 – 1320	1297 - 1316			
16. Zero Dispersion Slope, pc/nm^2•km	≤ 0.11πJ1R 1300 - 1320	≤ 0.11 πJ1R 1297 - 1316			
17. Numerical Aperture	0.200 ± 0.015	0.200 ± 0.012	0.2		

* Russian letters Deh, Ell, Ya; ** Russian letters Ee, Ell, Ee; *** Measured over about 10 meters **** based on 830 nm measurement and transmission spectrum

Sample ITF-47 is the multimode fiber that Paul Herman brought back from his July 1999 visit to Snezhinsk.

(1) C-70 Value, are the measurement data given to Paul with the sample. We understand that C-70 some of these measurements were made for C-70 by an organization in or near Moscow.

(2) LLNL Values: are the data taken by LLNL.

ITF-10.2 is the multimode fiber that Paul Herman brought back from his November 1998 visit. The table sent in November 1999 had a mistake for the ITF 10.2 attenuation. The attenuation was 2.4 db/km at 1550 nm. The value of 80 db/km at 1550 nm was for the multimode optical fiber brought by the C-70 delegation to Sandia Laboratory in August of 1998. The data from the ITF 10.2 and the single and multi-mode fiber from August 1998 was summarized in a report "C-70 Optical Fiber Measurements & Analysis" 11 June 1999 which Paul Herman delivered to Snezhinsk during his July 1999 visit.

Test Procedure

Five one-meter length samples were cut from the roll of optical fiber. One end of the fiber was then connected to the upper grip on the Instron test machine. The crosshead was lowered until there was 0.5 meters between the upper and lower grip. (gage length of 0.5 meters). The lower grip was attached. Data acquisition was started and the test ran until specimen failure. Typical measurements are on much longer (10's m) special fiber testing machine. These tests on shorter sections yield higher values

The ultimate strength was calculated using the average of the measured fiber diameter, Table 3. Please see Figure 1 for stress vs. strain curves of the five samples tested. Strain is defined as the grip separation (0.5 m) divided by total crosshead motion.

Table 2 Optical Fiber Coating Diameter

Sample	Diameter (μm)
1	268.5
2	265.1
3	269.2
4	280.7
5	266.1
Average	**269.9**
Standard Dev.	**6.2**

Table 3 Optical Fiber Ultimate Strength

Sample	Ultimate Strength (Gpa)
1	0.957
2	0.956
3	0.948
4	0.958
5	0.944
Average	**0.953**
Standard Dev.	**0.006**

Core and Cladding diameter

The attenuation of the fiber was measured using the cutback technique as described in the next section. Ten different measurements were made after cutting off a length of the fiber. The core and cladding of the fiber was measured on an optical microscope as each section of the fiber was removed. The maximum diameter was measured, and the diameter approximately perpendicular to the maximum was measured. The maximum was estimated first by eye and then measured. When a doubt existed if the diameter was the maximum, another measurement or two was made. The results for the core and cladding diameter and non-circularity are given as a function of length of where

the measurement is made in Table 4 & 5. The non-circularity is calculated using equation 1 in the same manner as in the standard *TIA/EIA-492AAAB (50 μm core, 125 μm cladding diameter).*

(3) Non-circularity = [1-{min diameter/maximum diameter}]*100

Table 4 Cladding Diameter and Non-Circularity as a Function of Position

Position (Length) (m)	Cladding 1 (μm)	Cladding 2 (μm)	Ellipticity= Cladding1/ Cladding2	Non Circularity
126	127.2	129.1	0.985	1.472
224	128.8	128.9	0.999	0.078
324	127.4	128.4	0.992	0.779
422	127.4	125.8	1.013	1.272
518	126.8	127.3	0.996	0.393
616	128.8	130.3	0.988	1.151
712	126.7	125.9	1.006	0.635
815	128.1	129.7	0.988	1.234
907	127.9	127.8	1.001	0.078
1215	129.1	129.7	0.995	0.463
Average	128.1			0.76
Std Dev	1.3			0.51

Table 5 Core Diameter, Non-Circularity, and Center Off-set as a Function of Position

Position (Length) (m)	Core 1 (um)	Core 2 (um)	Ellipticity= Core1/ Core2	Non Circularity	Center Offset (um)
126	52.8	52.8	1.000	0.000	1.47
224	55.3	55.5	0.996	0.360	0.49
324	52.7	52.7	1.000	0.000	0.68
422	53.8	54.8	0.982	1.825	0.00
518	56.1	55.2	1.016	1.630	0.81
616	52.4	51.8	1.012	1.158	1.20
712	50.3	50.1	1.004	0.399	0.49
815	50.8	51.6	0.984	1.550	0.00
907	51.0	51.1	0.998	0.196	0.65
1215	54.4	54.4	1.000	0.000	0.86
			Average	0.71	0.67
			Std Dev	0.74	0.46
	53.0	Average Diameter			
	1.9	Std Dev			

Figure 1 Stress vs Strain